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# A Preliminary Assessment of the Monostatic Acoustic Sounder as a Forecast Aid in the Prediction of Advection Fogs at a Massachusetts Coastal Station

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6 November 1980

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AIR FORCE SYSTEMS COMMAND, USAF

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

John Howard

Chief Scientist

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A monostatic acoustic sounder was installed at the AFGL Weather Test Facility at Otis AFB, Massachusetts. Data were collected during 18 fog cases that occurred during the 1979 fog season. These data were used to conduct a preliminary evaluation of the usefulness of the monostatic acoustic sounder for predicting the occurrence and dissipation of east coast maritime fogs, and to learn more about the structure and evolutionary processes of the fog life cycle. Results indicate that the inversion height data obtained from the sounder, and information on the lifting condensation level, can be used to predict the

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occurrence of stratus and the probability of a fog event. The sounder provides no information, however, that would be useful in predicting the onset time of the fog event. There is some evidence of turbulent mixing causing the fog to lift, and low level convergence causing the fog to form.

# Preface

The author is especially grateful to Stuart Sheets for his cooperation and support in installing and maintaining the acoustic sounder, and to Leo Jacobs, Ralph Hoar, and Clyde Lawrence for maintaining and operating the Weather Test Facility instrumentation and data system.

## Contents



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# A Preliminary Assessment of the Monostatic Acoustic Sounder as a Forecast Aid in the Prediction of Advection Fogs at a Massachusetts Coastal Station

## 1. INTRODUCTION

Much work has been done in the past toward obtaining a better understanding of the various mechanisms involved in the formation and dissipation of maritime fog along the west coast of the United States. Since the earliest study of Palmer,[1] other studies by Anderson,[2] Petterson,[3] Neiburger,[4] and Leipper[5] have been conducted. More recently, the U.S. Navy and various contractors have conducted extensive measurement programs off the California coast.[6-8] As a result of these programs, a rather complete understanding of the formation and dissipation mechanisms of the west coast fogs has been obtained.

Along the east coast of the North American Continent, very few fog studies have been conducted. Taylor[9] and Mack et al[10] conducted studies in the Atlantic off the coasts of Labrador and Nova Scotia, respectively. Aside from occasional microphysical measurements, such as those of Houghton and Radford[11] and Kunkel,[12] studies of fog along the United States east coast are nonexistent. This is surprising considering that the Atlantic region north of New Jersey is one of the foggiest areas worldwide and contains one of the busiest shipping lanes in the world. Also, fog is frequently advected inland in this area, causing major disruptions to air and ground traffic.

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(Received for publication 4 November 1980)

(Because of the large number of references cited above, they will not be listed here. See References, page 19.)

The purpose of this study is to evaluate the usefulness of the monostatic acoustic sounder for predicting the occurrence and dissipation of east coast maritime fogs. This is part of a larger effort that includes the collection and evaluation of drop-size data and the use of existing models to learn more about the structure and the evolutionary processes that take place during the fog life cycle. The ultimate objective is to improve short range fog forecasting techniques.

## 2. AFGL WEATHER TEST FACILITY (WTF)

The Air Force Geophysics Laboratory (AFGL) has established a Weather Test Facility (WTF) at Otis AFB, Falmouth, Mass., located on Cape Cod about 12 km inland from the south shore, as shown in Figure 1. The purpose of this facility is twofold: to evaluate new meteorological sensors and automated data systems, and to collect data for use in various short range forecast studies conducted at AFGL.

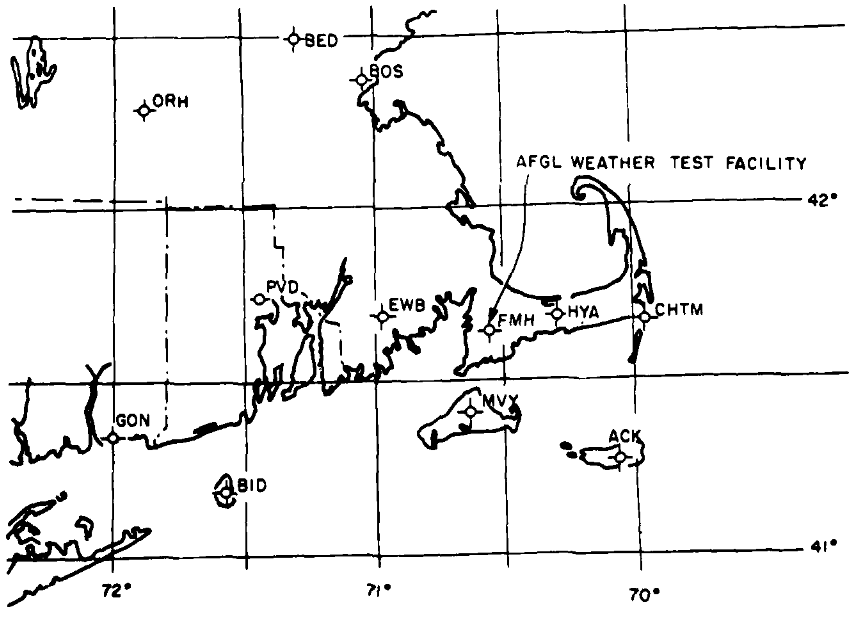


Figure 1. Location of the AFGL Weather Test Facility

The facility has an array of meteorological sensors located near the ground and on various 60-m and 30-m towers. Among the more important instruments are EG&G temperature-dewpoint sensors, EG&G forward scatter meters, rotating beam

ceilometers, Climatronic wind sensors, R. M. Young vertical wind sensors, PMS forward scattering and optical array drop-size probes, and an Aerovironment monostatic acoustic sounder. Except for the drop-size instrumentation and the acoustic sounder, the instruments run continuously and the data are recorded on magnetic tape.

## 3. FOG TYPES

There are two primary types of fog, as defined by Byers,[13] that occur at the WTF: advection and front-passage. Advection fogs occur either when the area is in the warm sector of a low or when the Bermuda high builds up off the Mid-Atlantic coast. Fog forms over the water south of Cape Cod when warm moist air is advected over the cold ocean waters. Radiational cooling maintains the fog as it moves inland at night. These fogs tend to be relatively shallow, that is, about 200 to 300 m in depth. Advection fogs are most common during the summer months.

Front-passage fogs occur when an occluded front, associated with a low pressure area over Northern New England or Canada, passes over the area. These fogs usually form at night after rain or showers have thoroughly wetted the ground. They are associated with a cloud layer that is at least 1000 to 2000 m in depth. This type of fog occurs year round, but is more common during the winter and spring seasons. Other types of fog also occur, but with much lower frequency. They are pre-warm frontal, post-cold frontal, and radiation fogs.

## 4. MONOSTATIC ACOUSTIC SOUNDER

The acoustic sounder, an Aerovironment Model 300, is designed to receive energy backscattered from regions of small scale (~10 cm) temperature inhomogeneities. This temperature microstructure is associated with turbulence within a region of the atmosphere that generally has a non-neutral vertical temperature gradient. Maximum echoes are normally received from the top of a mixed layer and in stable flow when there are significant shears. The sounder emits a 1600 Hz pulse and has a vertical range of 1000 m with a resolution of 17 m. A stylus moves across the recorder facsimile chart paper and darkens the chart when an echo is received. The result is a time-height plot that identifies the turbulent layers in a non-neutral stability region.

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13. Byers, H. R. (1944) General Meteorology, McGraw-Hill Book Co., Inc., 645 pp.

## 5. DATA ANALYSIS

During the 1979 fog season, data from the sounder and from the other instrumentation at the WTF were collected on a continuous basis. Data were obtained from a total of nine advection fog cases and nine front-passage fog cases. When the wind was off the water, which was the majority of the time, the acoustic sounder data showed continuous echoes at night between 100 and 300 m above the ground. During the daytime, the convective activity causes the echo layer to rise to the 300- to 600-m level or to disappear completely. This echo layer represents the capping inversion over the marine boundary layer. In some advection fog situations, the capping inversion is further intensified by subsidence aloft. Temperature increases in the inversions are typically 5°C, but they may be as high as 10°C when subsidence is present.

Figure 2 shows a comparison of the acoustic sounder records during an advection and a front-passage fog case. Also shown are the extinction coefficients measured with the EG&G forward scatter meter at the 15 m level. The extinction coefficient ($\sigma$) is a measure of the atmosphere's capacity for transmitting light, and is related to the visual range (V) by the formula

$$\sigma = \frac{3.912}{V} .$$

The acoustic sounder records obtained during frontal fogs were generally characterized by occasional darkened areas over the entire 1000 m range, resulting from showers hitting the receiver, and by weaker multiple echo layers above the main inversion layer. In the frontal fog case shown in Figure 2, the inversion layer appears to reach the ground near midnight. This surface inversion was observed from 0040 to 0130 EST in the direct temperature measurements made on a 60 m tower. A maximum positive gradient of 0.6°C over the 60 m depth was measured at 0100 EST. Later, when the inversion layer was above the ground, the tower measurements indicated a near neutral stability condition. After sunrise at 0440, thermal convective activity, indicated by the spikes, caused the inversion layer to lift.

The advection fog event, depicted in Figure 2, occurred in the warm sector of a low pressure system centered in Quebec. Fog that formed over the waters south of Cape Cod was advected into the WTF area on southwest winds shortly after sunset. As in the frontal fog case, the inversion layer was centered between 100 and 300 m. The temperature data from the 60 m tower indicated a neutrally stable condition below the inversion.

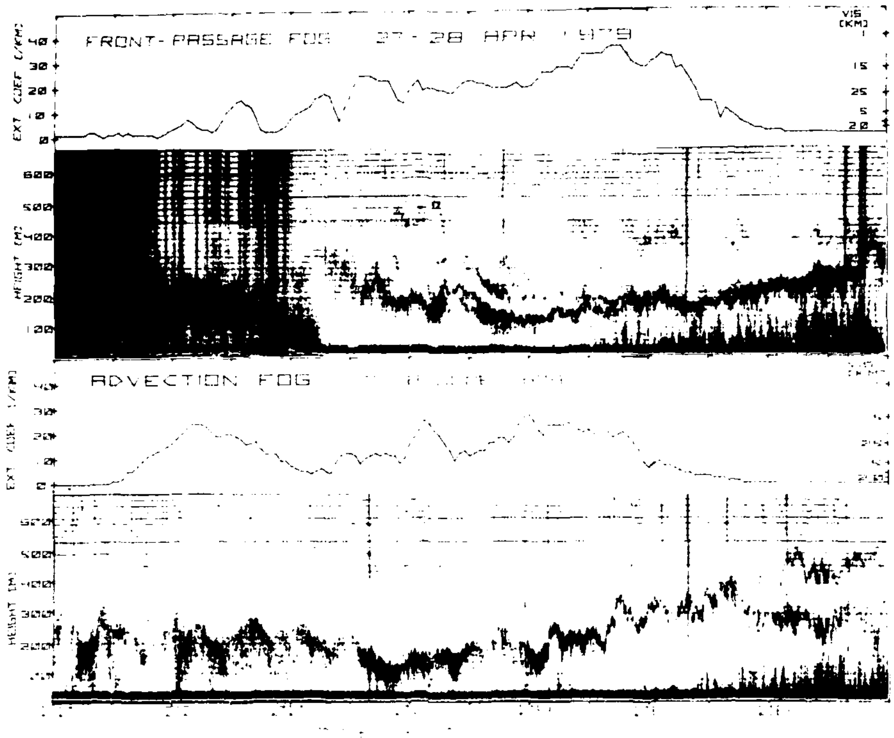


Figure 2. Acoustic Sounder Record and Extinction Coefficients Measured at the 15 m Level During a Front-Passage Fog and an Advection Fog. The extinction coefficient measurements were made with an EG&G forward scatter meter

The acoustic echo layer normally represents the top of the fog layer in the advective fog situations, but does not necessarily represent the top of the fog layer in the front-passage type fogs. Figure 3 shows an example of the vertical temperature and moisture profile data as obtained from the Chatham radiosonde, located 50 km east of the WTF, during an advection and a frontal fog case. In the advection fog case, the top of the fog is near the base of the capping inversion. In the frontal fog situation, the moist layer, and presumably the clouds, extends up to an elevation of 1500 m. The height above sea level of the inversion top, as determined by the acoustic sounder, is also shown. Good agreement in the inversion height data was normally found between the radiosonde and the acoustic sounder.

The acoustic sounder records were examined with two objectives in mind: to determine if, and how, the data could be used to improve fog prediction techniques; and to learn more about the fog structure and its evolutionary processes by examining the data in conjunction with the WTF data. In this study, only the nine advection fog cases were analyzed.

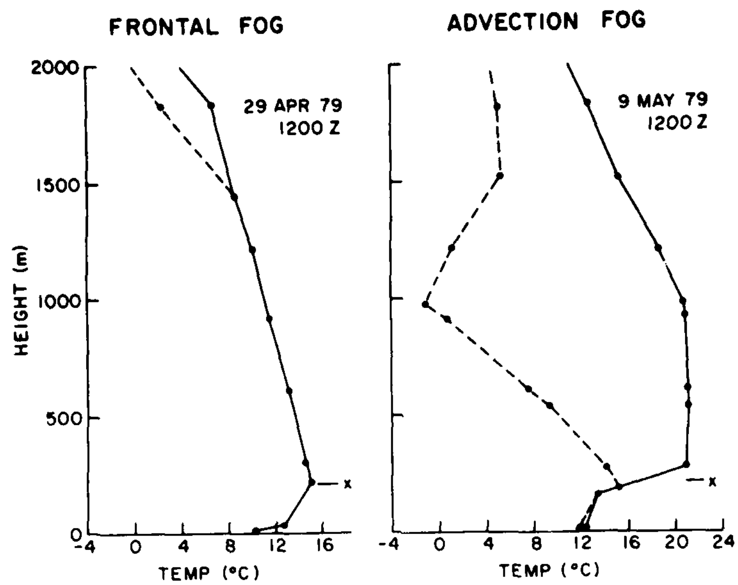


Figure 3. Radiosonde Data Taken at Chatham, Mass., During a Frontal and an Advection Fog. The height of the inversion top as determined by the acoustic sounder is also shown

In reference to the first objective, examination of the data revealed no obvious changes in the characteristics of the acoustic sounder records preceding the occurrence or dissipation of fog that could be used as a forecast tool. However, the acoustic echo height data, in conjunction with the surface temperature and dewpoint data, were helpful in predicting the formation of stratus, which normally precedes the occurrence of fog. Stratus forms when the lifting condensation level (LCL), determined from the surface temperature and dewpoint, lowers to a level well within the echo layer. Figure 4 shows three examples of the lowering LCL and the time at which stratus was first observed, as indicated by the arrows.

Predicting when the stratus will lower to the ground is a more difficult problem. The acoustic sounder provided no new information that would be of help in predicting the descent rate of the stratus. In the cases examined, there was no evidence of a correlation between the height of the stratus formation and the time it took for the stratus to lower to the ground.

The acoustic sounder may be of value in predicting the probability of fog occurrence. The cases examined suggest that when the inversion height is above some critical height (~300-400 m), the likelihood of the stratus lowering to the ground is very slight. Figure 5 shows an example of a relatively high inversion of 200 to 300 m. Stratus formed at 2100 EST but did not lower to the 60 m level for 4 hours, and then only remained for a short period of time. At the 4 m level the extinction coefficient only reached a value of 10 $km^{-1}$, or a visual range of 400 m.

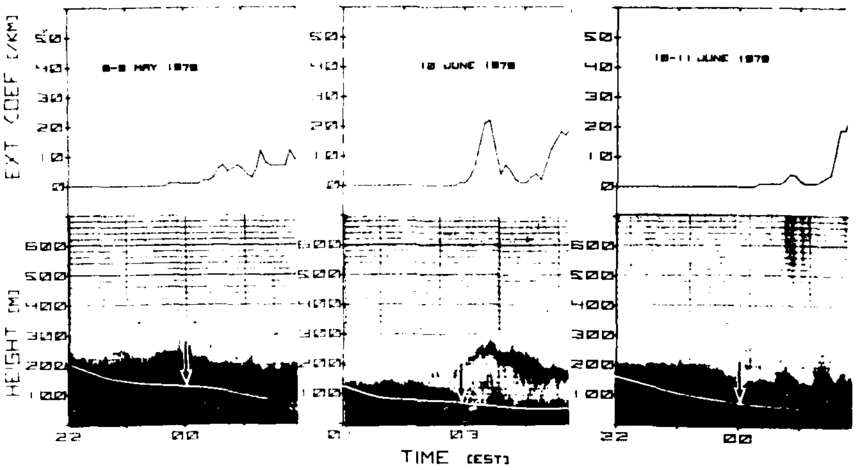


Figure 4. Examples of the Lowering of the LCL and the Formation of Stratus (denoted by the arrow)

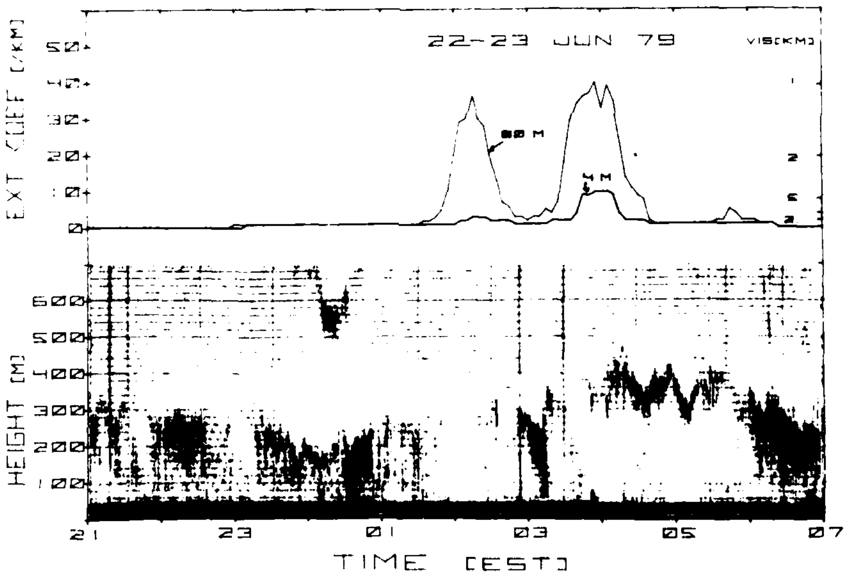


Figure 5. Acoustic Sounder Record and Extinction Coefficient Measurements at the 4 m and 60 m Levels During a 10 Hour Period on 22-23 June 1979

The second objective of learning more about the fog structure and evolution was addressed by examining changes in the visibility in the lower 60 m in relation to changes in the height and/or intensity of the echo layer. In most cases, however, changes in visibility were not accompanied by changes in the acoustic sounder record. It was quite apparent, though, that in cases when the visibility in fog remained relatively constant, the intensity and height of the echo layer also remained relatively constant, as shown in Figure 6. In other cases, when rapid changes in visibility occurred, the echo height varied considerably, as shown in Figure 7. Figures 6 and 7 show the extinction coefficient at the 60 m level. The behavior of the extinction coefficient at other levels closer to the ground was similar but their values were lower. Generally, the fluctuations in the echo height and extinction coefficients did not appear to be correlated. However, in the case shown in Figure 7 there does appear to be a lifting of the inversion layer when the visibility increases. This may possibly indicate that vertical mixing is taking place during these times, although there were no noticeable changes in the vertical wind speed as measured by the R. M. Young vertical wind sensors.

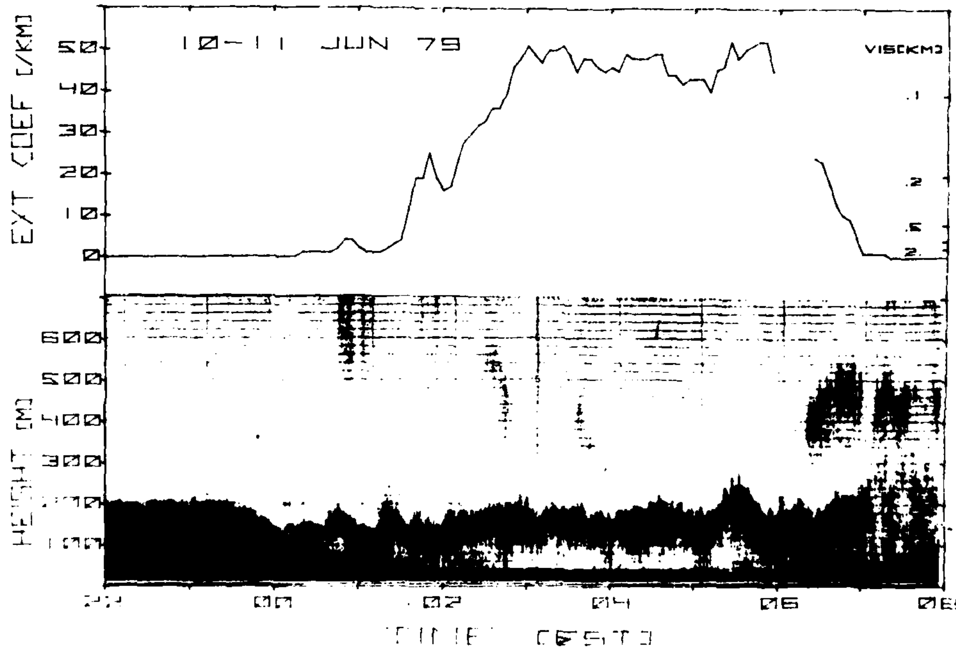


Figure 6. Acoustic Sounder Record and Extinction Coefficients Measured at the 60 m Level During a 10 Hour Period on 10-11 June 1979

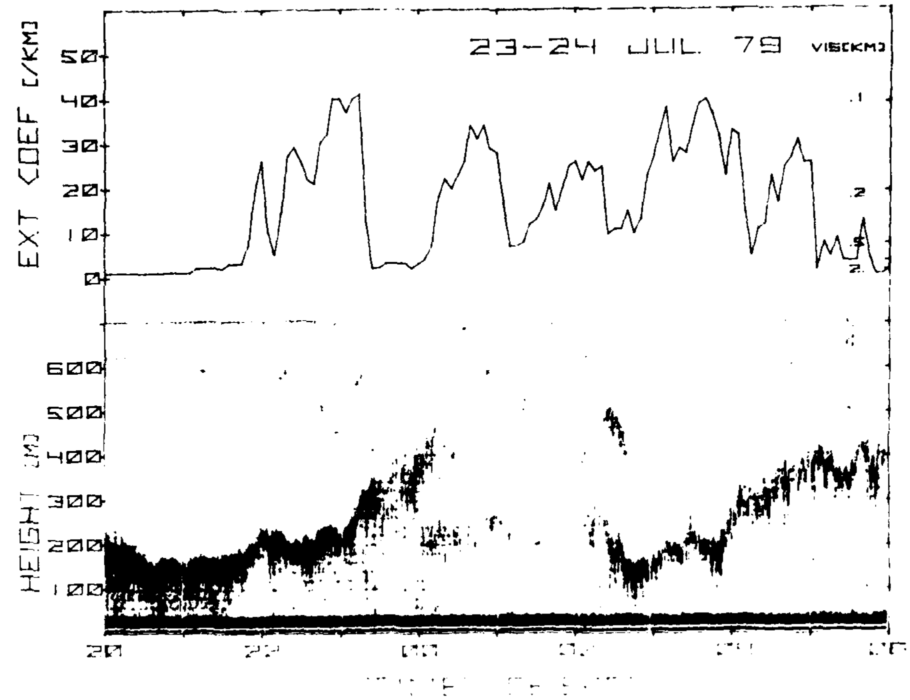


Figure 7. Acoustic Sounder Record and Extinction Coefficients Measured at the 60 m Level During a 10 Hour Period on 23-24 July 1979

In another case that occurred on the night of 23-24 October 1979 (Figure 8), fog formed during an otherwise clear night and remained for about 1 hour. The fog formed at the same time that the top of the echo layer increased from 160 to 210 m. An examination of the vertical wind speed at the 45 m level (Figure 9) shows an increase in upward velocity from about 9 cm/sec to 18 cm/sec during the fog, then returning to 9 cm/sec after the fog dissipated or advected out of the area. This may be a case of fog being formed by low-level mesoscale convergence and uplifting, documented for the first time by Pilie et al.[14]

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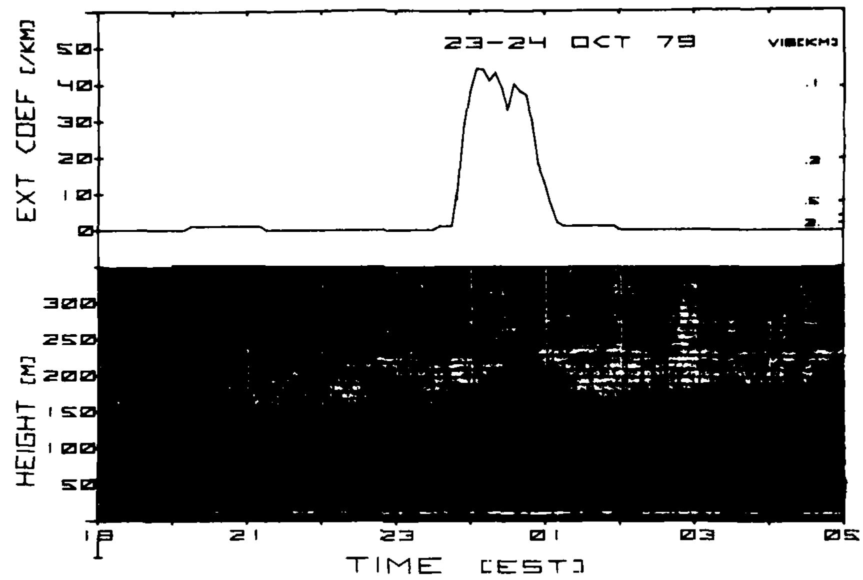


Figure 8. Acoustic Sounder Record and Extinction Coefficients Measured at the 60 m Level During a 10 Hour Period on 23-24 October 1979

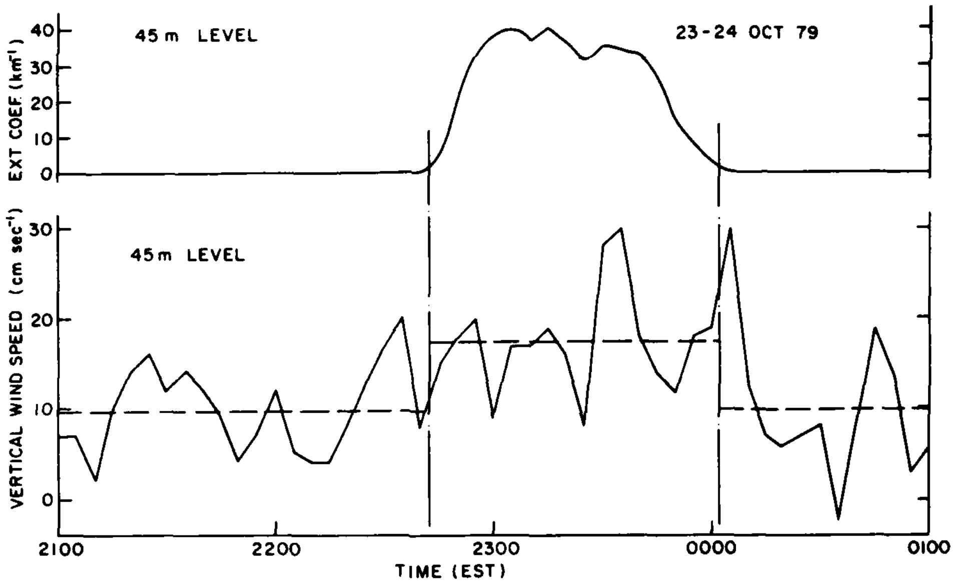


Figure 9. Vertical Wind Measurements During a Fog on 23-24 October 1979. Measurements were taken at the 45 m level with an R. M. Young wind sensor

## 6. CONCLUSIONS

Some preliminary conclusions can be derived from the fog cases that were analyzed:

- The temperature inversion does not necessarily represent the top of the fog layer. In the case of front-passage fogs, the moist air may extend well above the temperature inversion or marine layer.
- The output of the acoustic sounder in combination with the surface temperature and dew point may be useful in predicting the formation of stratus preceding advection fogs. Stratus generally forms when the lifting condensation level drops to a level well within the echo layer.
- The acoustic sounder may be useful in predicting the probability of the formation of advection fog by providing information on the inversion height. However, there is no evidence that it provides any information that would be helpful in predicting when the stratus will lower to the ground.
- There is some evidence that, on occasion, the mechanisms that cause fog to form and dissipate also cause the echo layer to shift. These mechanisms could be vertical mixing and low level mesoscale convergence. However, more cases and data are required to confirm that these mechanisms are factors and to determine the frequency with which these mechanisms affect the formation and dissipation of fog.

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